Effects of shielded spray of paraquat and glyphosate on the growth and yield of corn (*Zea mays* L.)[1]

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ABSTRACT : Field experiments were conducted in the fall crop of 1990 and the spring crop of 1991 to evaluate growth and yield of corn (*Zea mays* L. cv. Tainung No.1) in responses to paraquat and glyphosate, with or without shielding, applied at three different times in the vegetative stage. Although weed control was improved, herbicide applications at 2, 4 or 6 weeks after planting (WAP) slightly reduced corn growth and yield relative to those of handweeding treatments, but higher than the weedy check. Without proper shielding, the growth and yield of corn was further decreased due to plant injury. Compared to the shielded ones, plant height and leaf area of unshielded corn plants at the 50% silking were declined more than 10% and 20% by paraquat and 15% and 25% by glyphosate applied at 2, 4 or 6 WAP in both 1990 and 1991. Whereas, more than 50% and 60% corn yield reductions were found by applications of paraquat and glyphosate, respectively, in the two seasons. When analyzing the yield characters, it was shown that, without shielding, ear weight and kernel weight were decreased in the spring crop. The effective plant percentage (EPP) was affected by herbicide applications, especially under unshielded conditions. Weed control practices applied as early as 2 WAP ensuing uniform tasseling and silking while glyphosate lengthened the 50% tasseling and silking dates when applied without shielding before 4 WAP. It is therefore suggested that applications of paraquat and glyphosate, if necessary, in the corn field should be with proper shieldings to eliminate corn injury.
Nomenclature : Paraquat, 1, 1'-dimethy 1-4, 4'-bipyridinium dichloride ; glyphosate, N- (phosphonomethyl) glycine.

Key Words : paraquat, glyphosate, corn, growth, yield, application timing, application method.

Introduction

Applications of synthetic herbicides on weed control programs are prevailing in modern agriculture. In corn, preemergence herbicides such as atrazine, metolachlor and pendimethalin are recommended in normal cultivation practices in Taiwan (Anonymous, 1990 ; Chiang and Leu, 1987). However, some postemergence herbicides such as paraquat and glyphosate may also be used to control the weedy fields.

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Paraquat, often used in early postemergence, is one of the most economical, efficacious and non-selective weed-controlling herbicide (Stall et al., 1987 ; Wehtje et al., 1986 ; Wilcut et al., 1989 ; Wilcut and Swann, 1990). When applied postemergence, paraquat was found to cause foliar injury of peanut (Wehtje et al., 1986). Fedtke (1982) further pointed out that paraquat induces rapid membrane deterioration through generation of superoxide radicals.

Glyphosate, a nonselective, broad-spectrum, postemergence, phosphonic acid herbicide (Duke, 1988 ; Franz, 1985), is anionic in nature and has a higher water solubility. Glyphosate is used to control perennial as well as annual weeds because of its rapid translocation and high phytotoxicity (Baird and Begeman, 1972). Glyphosate is readily taken up by plants from source leaves to physiologically active sinks, commonly accumulates in the apices of shoot and root (Claus and Behrens, 1976 ; Kells and Rieck, 1979 ; Sprankle et al., 1975), and translocated in both xylem and phloem (Duke, 1988). Duke (1988) also indicated that glyphosate is degraded only slightly in plants and often is slow acting.

Little research has been carried out to illustrate effects of paraquat and glyphosate on crop growth and yield as influenced by application timing and method. Understanding of such effects would be highly beneficial to improve the knowledge of crop response and herbicide efficacy. Corn injury from the misapplication and drift of these herbicides can be expected due to the close vicinity of corn to weeds. The assessment of growth injury and yield reduction of corn caused by mispractices provides essential information for adequately using of these herbicides.

This study was conducted to investigate the consequences that may result from the exposure of corn crop to paraquat and glyphosate at the different application timings and with or without shielding, and yields of corn that may be harvested from the original planting by herbicide applications.

Materials and Methods

Field experiments were conducted at the experimental farm of Taiwan Agricultural Research Institute (TARI, 24° 02′ N, 120° 40′ E, elevation 85 m) on a silt loam soil (fine-loamy, mixed, nonacid, hyperthermic, Fluvaquentic Dystroochrept) in Fall crop, 1990 and Spring crop, 1991. The soil contained 33.1% sand, 50.2% silt, and 16.6% clay with 1.8% organic matter and 5.5 of pH. Corn cultivar 'Tainung No. 1', obtained from Taiwan Seed Service (Ta-nan village, Shinshieh, Taichung, Taiwan, ROC), was planted on September 14, 1990 and March 4, 1991, and was seeded at a depth of about 4 cm with plant distance of 25 cm. Individual plots (subplots) were eight rows spaced 70 cm apart and 7.0 m long. Separate experimental areas were used, for rotation purpose, in different seasons and were rotary plowed prior to cultivation. The experimental area was treated with 130 kg ha^{-1} N, 70 kg ha^{-1} of P_2O_5 and 50 kg ha^{-1} of K_2O each crop. Fertilizer (50—70—50 ; N, P, K) was applied onto the soil surface at planting and the rest of nitrogen was applied with the equivalent at 3 and 6 weeks after planting (WAP).

Paraquat (24% solution, 3 L ha^{-1}) and glyphosate (isopropylamine formulation of 41% solution, 5 L ha^{-1}) were directly applied near the ground and between-the-row in water volume of 200 L ha^{-1} using a CO_2-pressurized, backpack sprayer at 2, 4, or 6 WAP separately. Two wooden plates of 50 cm wide and 7.0 m long were used for shielding purpose. Results of herbicide applications were evaluated using handweeding treatments and weedy check for comparison. Plant height and leaf area per plant were measured at the 50% silking. Plant height was measured from the soil surface to the highest point of plant with a ruler and the leaf area was determined by an area meter (LI−3000, Li-Cor, INC., Nebraska, USA). Corn survival ratings were based on the effective plant percentage (EPP) at harvest, determined by counting the number of plants with ear (s) in each plot relative to the planted number expressed as a percent of the planted number. Corn yields were estimated by the fresh weights of ears (without husk) taken from the center four rows of each eight-row plot by hands. Samples of corn, 6 plants for each replication, were harvested from the rest rows to determine ear length, ear fresh and dry weights, and kernel dry weight (80° C for 72 h) . Before corn harvest, the number of weeds per square meter and their dry weights (80° C for 72 h) for each plot were taken. Weed populations were the result of natural infestations.

The trial was a split-plot design replicated three times with application timings as main plots and herbicide (with or without shielded) and handweeding treatments as subplots. Corn yields were separated by crop. Data were subjected to analysis of variance and means were compared with Fisher's Least Significant Difference (LSD) Test at the 5% level of probability. The standard errors were also computed.

Results

Relative to those of handweeding treatments at the same time, corn height, measured at the 50% silking, was slightly reduced by herbicide applications at 2, 4, or 6 weeks after planting in Fall crop 1990 and Spring crop 1991 (Figure 1), but higher than the weedy check. Corn height was further reduced, more than 15% by glyphosate in both seasons and 15 and 10% by paraquat in 1990 and 1991, when without proper shielding. Leaf area followed the similar trend. At the 50% silking, leaf area of the plants applied by herbicides slightly lowered than those of handweedings but greater than the weedy check (Figure 2). Leaf area was significantly decreased in the unshielded plants. About 35, 25, and 20% and 45, 30 and 25% reductions were calculated by applications of paraquat and glyphosate at 2, 4, or 6 WAP, respectively, in both years.

Corn yield, expressed by the fresh weight of corn ears at harvest, was not changed by herbicide treatments when shielded (Table 1). Without proper shielding, however, corn yields were significantly reduced, especially when herbicides were applied in the early vegetation. Ear length, ear weight and kernel weight were not affected by herbicide applications, with or without shielded in the fall crop (Table 2). Ear and kernel weights were decreased in unshielded corn in the spring crop. The effective plant percentage (EPP) was strongly declined by the applications of paraquat and glyphosate without shielding in both crops, the younger the plant the stronger the harmful effect.

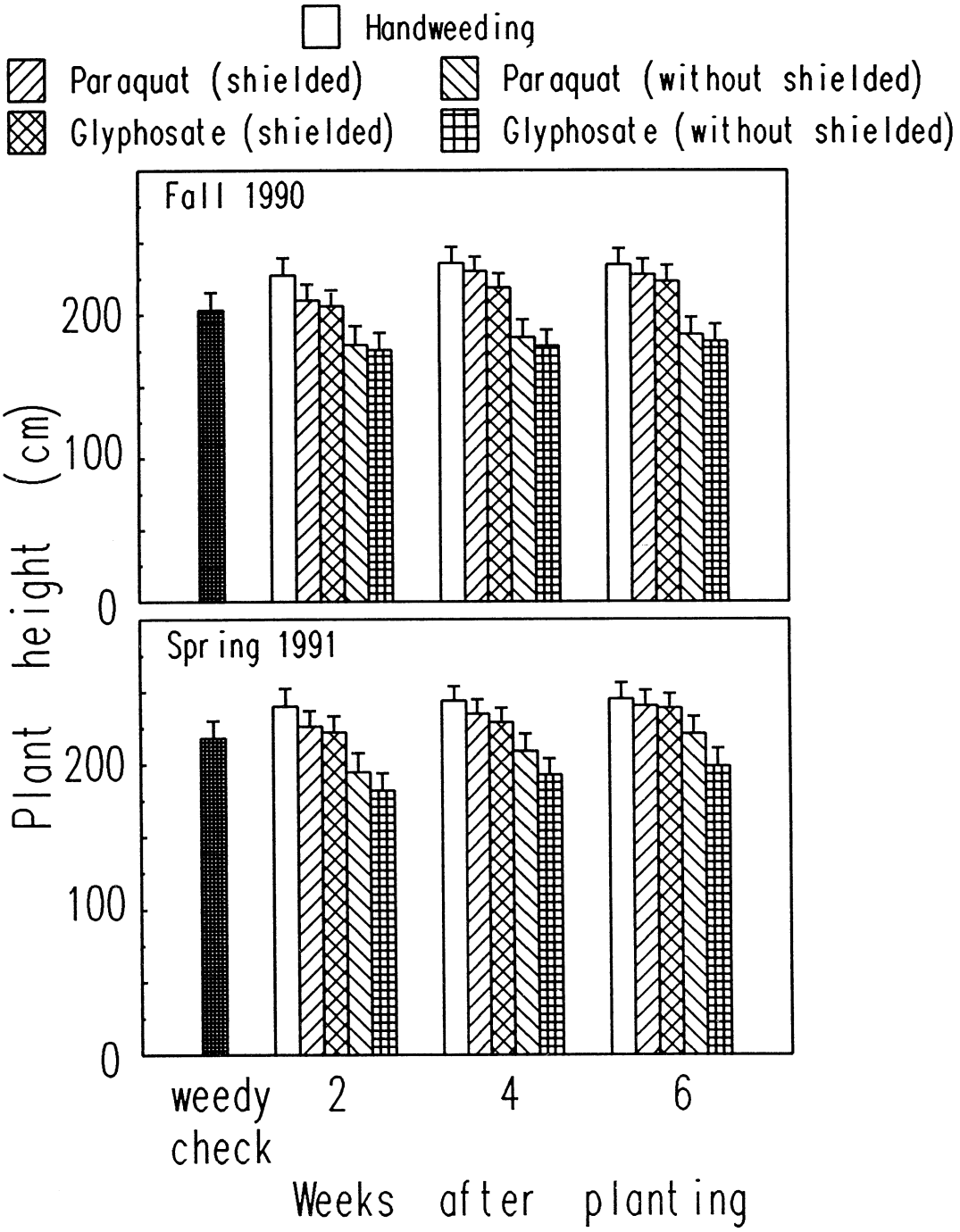

Fig. 1. Effects of paraquat and glyphosate on plant height of corn as influenced by timing and method of application in the fall crop of 1990 and spring crop of 1991.

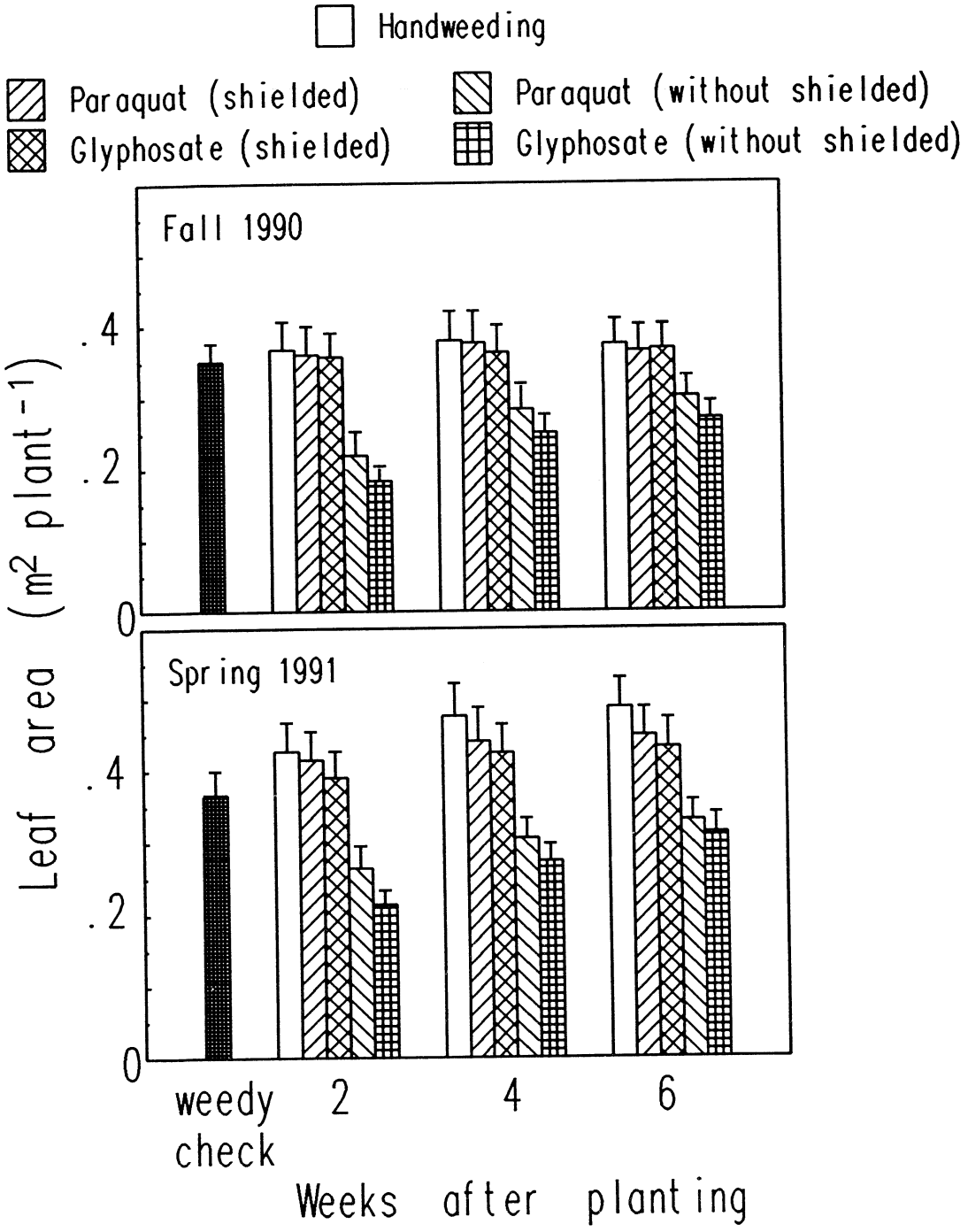

Fig. 2. Effects of paraquat and glyphosate on leaf area of corn as influenced by timing and method of application in the fall crop of 1990 and spring crop of 1991.

Table 1. Effects of paraquat and glyphosate or handweeding on the fresh weight of corn ears (without husk) as influenced by application timing and method.

Time of application	Herbicide treatment	Shielding	Ear fresh weight	
			Fall 1990	Spring 1991
WAP@			·····kg ha^{-1}·····	
2	Paraquat	Yes	9,740	10,970
		No	2,240	2,720
	Glyphosate	Yes	9,080	10,830
		No	2,040	2,140
	Handweeding		9,810	11,310
4	Paraquat	Yes	10,320	12,530
		No	3,580	4,720
	Glyphosate	Yes	9,490	12,200
		No	2,240	2,880
	Handweeding		10,710	12,930
6	Paraquat	Yes	10,050	12,750
		No	4,450	5,780
	Glyphosate	Yes	9,660	12,470
		No	3,400	4,850
	Handweeding		10,320	13,030
Weedy check			8,910	10,190
LSD@@ (0.05)			940	1,260

@ WAP : weeks after planting.
@@Fisher's Least Significant Difference Test at the 5% probability level.

Table 2. Effects of paraquat and glyphosate or handweeding on the yield characters of corn as influenced by application timing and spray method.

Time of application	Herbicide treatment	Shielding	ear lenght	ear fw	ear dw	kernel dw	EPP@
WAP@@			cm	·····g pl^{-1} ·····			
Fall crop, 1990							
2	Paraquat	Yes	18.3	190.5	97.4	77.3	90.4
		No	17.3	183.5	93.2	72.7	21.3
	Glyphosate	Yes	17.9	186.1	96.9	77.1	86.8
		No	17.1	182.5	93.1	72.3	19.5
	Handweeding		18.1	190.1	97.2	76.6	92.1
4	Paraquat	Yes	18.8	198.1	101.3	80.6	91.2
		No	17.7	186.6	96.6	77.1	33.6
	Glyphosate	Yes	18.2	189.2	96.6	77.5	88.2
		No	17.5	184.4	93.8	72.3	21.3
	Handweeding		18.6	199.2	102.9	81.5	94.1
6	Paraquat	Yes	18.6	196.4	99.1	79.9	91.9
		No	18.1	188.2	96.8	77.4	41.4
	Glyphosate	Yes	18.2	188.3	96.3	76.9	91.2
		No	17.5	185.2	93.2	72.1	32.2
	Handweeding		18.7	197.1	99.0	78.5	92.8
Weedy check			17.8	178.2	90.1	70.1	87.5
LSD@@@ (0.05)			0.6	9.0	8.0	7.3	6.3

Spring crop, 1991							
2	Paraquat	Yes	18.4	215.9	124.5	106.0	88.9
		No	17.6	178.3	97.6	78.1	26.7
	Glyphosate	Yes	18.3	213.2	124.5	105.8	88.9
		No	17.7	181.0	100.4	80.4	20.7
	Handweeding		18.4	218.8	123.4	106.0	94.8
4	Paraquat	Yes	18.7	230.7	131.9	113.4	95.0
		No	18.2	216.6	117.4	94.8	38.1
	Glyphosate	Yes	18.6	229.2	130.4	111.3	93.2
		No	18.11	212.3	115.2	92.5	23.7
	Handweeding		18.8	235.4	136.3	117.3	96.2
6	Paraquat	Yes	18.6	233.1	135.9	116.6	95.8
		No	18.3	220.5	122.4	98.7	45.7
	Glyphosate	Yes	18.5	231.4	132.7	113.8	94.3
		No	18.2	218.4	120.0	97.0	38.9
	Handweeding		18.8	236.7	137.3	118.4	96.3
Weedy check			17.9	197.9	117.0	99.5	90.1
LSD (0.05)			0.7	11.2	10.8	9.9	8.2

@ EPP : effective plant percentage.
@@ WAP : weeks after planting.
@@@Fisher's Least Significant Difference Test at the 5% probability level.

Generally the 50% tasseling and silking dates were not influenced by weed control practices, herbicides or handweeding, applied as early as 2 WAP (Table 3). However, glyphosate applied without shielding before 4 WAP lengthened the flowering periods. Weed density and weed dry weight determined at harvest were significantly decreased by weed control practices (Table 4), particularly with herbicides.

Table 3. Effects of paraquat and glyphosate or handweeding on the 50% tasseling (T) and the 50% silking (S) dates of corn as influenced by application timing and method.

Herbicide	Time of application	Shielding	Fall 1990@		Spring 1991@@	
			50% T	50% S	50% T	50% S
	WAP@@@					
Paraquat	2	Yes	Nov. 15	Nov. 18	May 11	May 13
	2	No	Nov. 15	Nov. 19	May 11	May 14
Glyphosate	2	Yes	Nov. 15	Nov. 18	May 11	May 13
	2	No	Nov. 20	Nov. 25	May 16	May 20
Handweeding	2		Nov. 15	Nov. 18	May 11	May 13
Paraquat	4	Yes	Nov. 14	Nov. 17	May 10	May 12
	4	No	Nov. 14	Nov. 18	May 10	May 13
Glyphosate	4	Yes	Nov. 14	Nov. 17	May 11	May 13
	4	No	Nov. 19	Nov. 24	May 16	May 20
Handweeding	4		Nov. 14	Nov. 17	May 10	May 12
Paraquat	6	Yes	Nov. 14	Nov. 17	May 10	May 12
	6	No	Nov. 14	Nov. 17	May 10	May 12
Glyphosate	6	Yes	Nov. 14	Nov. 17	May 11	May 13
	6	No	Nov. 14	Nov. 18	May 11	May 14
Handweeding	6		Nov. 14	Nov. 17	May 10	May 12
Weedy check			Nov. 16	Nov. 20	May 11	May 14

@ Planting date : September 14, 1990.
@@ Planting date : March 4, 1991.
@@@WAP : weeks after planting.

Table 4. Effects of paraquat and glyphosate or handweeding on weed density (WD) and weed dry weight (WDW) at corn harvest as influenced by application timing and method.

Herbicide	Time of treatment	Shielding	Fall 1990		Spring 1991	
			WD	WDW	WD	WDW
	WAP@		pl m^{-2}	g m^{-2}	pl m^{-2}	g m^{-2}
Paraquat	2	Yes	142	42.5	124	31.9
	2	No	122	37.0	106	27.9
Glyphosate	2	Yes	132	38.7	120	30.5
	2	No	108	36.3	96	26.6
Handweeding	2		243	78.4	170	52.3
Paraquat	4	Yes	101	36.4	98	27.1
	4	No	85	31.6	84	25.9
Glyphosate	4	Yes	88	30.3	92	26.1
	4	No	66	24.5	70	24.1
Handweeding	4		149	42.3	118	30.8
Paraquat	6	Yes	87	31.1	80	26.6
	6	No	73	26.5	69	23.3
Glyphosate	6	Yes	69	25.1	68	23.8
	6	No	55	22.4	54	18.1
Handweeding	6		115	38.6	93	27.6
Weedy check			309	129.4	252	89.9
LSD@@ (0.05)			15	4.8	13	3.5

@ WAP : weeks after planting.
@@Fisher's Least Significant Difference Test at the 5% probability level.

Discussion

Paraquat and glyphosate are two widely used herbicides in weed control programs in Taiwan due to their non-seclective and broad-spectrum properties and rapid efficacy. Mispractices of these herbicides on crops may induce severe plant injury. Wehtje et al. (1986) reported that the drift of paraquat to peanuts results in foliar injury. Glyphosate was found to reduce both sugarcane yield and sugar yield at the concentration of 0.2 kg ha^{-1} and above (Richard, Jr., 1991). This study was carried out to investigate effects of paraquat and glyphosate on corn growth and yield as influenced by application timing and method. Such information is crucial to proper weed management, with maximum weed control while avoiding crop injury.

The results indicated that applications of paraquat and glyphosate, with or without shielding, at 2, 4, or 6 weeks after planting reduced weed density and weed dry weight in corn fields, relative to the handweeding counterparts. However, the growth and yield of corn was compensated due to plant injury. Both plant height and leaf area measured at the 50% silking were slightly reduced by herbicide applications. Without shielding, the additional 15 % and 15 and 10% reductions of plant height were observed by the influence of glyphosate and paraquat, respectively, in 1990 and 1991. More than 20 and 25% reductions of leaf area were calculated by applications of paraquat and glyphosate, respectively, in both years.

It was no surprise that corn yield was decreased. Compared to the shielded plants, less than 25, 40, and 45% and 25, 25 and 40% of corn yields were harvested when paraquat and glyposate, respectively, were applied without shielding at 2, 4, or 6 WAP due to severe plant injury. The effective plant percentage was significantly reduced, which was the primary factor causing yield reduction, in addition to the decrease of ear weight and kernel weight. With maximal value of about 45% of the EPP can only be expected if these herbicides were applied before 6 WAP. Nevertheless, except in the cases of glyphosate applied without shielding before 4 WAP, weed control practices applied as early as 2 WAP would ensure uniform tasseling and silking.

As a result, paraquat and glyphosate applied in the early vetgetative stage of corn are not recommended. Proper shielding should be carried out to eliminate corn injury if the applications of these two herbicides are indispensable.

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巴拉刈及嘉磷塞噴施期和噴施法對玉米生長與產量之影響[1]

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摘 要

本文旨在調查與比較殺草劑巴拉刈〔(paraquat), 1, 1′-dimethy-4，4′-bipyridinium dichloride〕；及嘉磷塞〔(glyphosate), N-（phosphonomethyl）glycine〕噴施期和噴施法對玉米臺農一號生長與產量之影響。田間試驗係在臺灣省農業試驗所農場，分別於1990年秋作及1991年春作進行。相對於同期人工除草處理者，在玉米播種後2，4及6週噴施巴拉刈（24%溶液，3公升／公頃）及嘉磷塞（41%溶液，5公升／公頃）雖然具有較佳除草效果，玉米生長與產量則受到抑制。若未經遮蔽保護措施直接噴施於田間，將因造成植株傷害而進一步降低玉米生長與產量。與遮蔽保護措施者相互比較下，噴施巴拉刈及嘉磷塞後於50%吐絲期時所測得之株高與葉面積在1990年及1991年分別下降超過10%及20%和15%及25%。但是，兩季產量均分別減少50%和60%。經過產量分析後發現，穗重、籽粒重及有效株數百分比在春作皆因噴施此兩種殺草劑而降低，尤以後者爲然。秋作則以有效植株百分比減少爲主。未經遮蔽保護措施者更行嚴重。除了嘉磷塞在玉米播種後4週前噴施者外，本試驗之各種除草處理及除草時期均未明顯改變達到50%雄穗開花及雌穗吐絲所需要時間。綜此結果顯示，巴拉刈及嘉磷塞不適合在玉米營養生長初期作爲除草藥劑，因故必須使用時，當施予適當遮蔽保護措施以減少玉米植株傷害。

關鍵詞：巴拉刈、嘉磷塞、玉米、生長、產量、噴施期、噴施法。

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